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Standard Guide for Reducing the Risk of Deleterious Alkali-Aggregate Reaction In Concrete¹

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1. Scope²

1.1 This guide provides guidance on how to address the potential for deleterious alkali aggregate reaction (AAR) in concrete construction. This guide addresses the process of identifying both potentially alkali-silica reactive (ASR) and alkali-carbonate reactive (ACR) aggregates through standardized testing procedures and the selection of mitigation options to minimize the risk of expansion when ASR aggregates are used in concrete construction. Mitigation methods for ASR aggregates are selected using either prescriptive or performance-based alternatives. Preventive measures for ACR aggregates are limited to avoidance of use. Because the potential for deleterious reactions depends not only on the concrete mixture but also the in-service exposure, guidance is provided on the type of structures and exposure environments where AAR may be of concern.

1.2 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system should be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This International standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

¹ This guide is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.50 on Aggregate Reactions in Concrete.

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2. Referenced Documents

2.1 ASTM Standards³

- C33/C33M Specification for Concrete Aggregates
- C114 Test Methods for Chemical Analysis of Hydraulic Cement
- C125 Terminology Relating to Concrete and Concrete Aggregates
- C150/C150M Specification for Portland Cement
- C219 Terminology Relating to Hydraulic and Other Inorganic Cements
- C294 Descriptive Nomenclature for Constituents of Concrete Aggregates
- C295/C295M Guide for Petrographic Examination of Aggregates for Concrete
- C311/C311M Test Methods for Sampling and Testing Fly Ash or Natural Pozzolan for Use in Portland-Cement Concrete
- C586 Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates (Rock-Cylinder Method)
- C695/C695M Specification for Blended Hydraulic Cements
- C618 Specification for Coal Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
- CR23/CR23M Practice for Examination and Sampling of Hardened Concrete in Constructions
- CR56 Practice for Petrographic Examination of Hardened Concrete
- C989/C989M Specification for Slag Cement for Use in Concrete and Mortars
- C1105 Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction
- C1157/C1157M Performance Specification for Hydraulic Cement
- C1240 Specification for Silica Fume Used in Cementsitious Mixtures
- C1260 Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

³ For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For Annual Book of ASTM Standards volume information, refer to the standard's Document Summary page on the ASTM website.

² A Summary of Changes section appears at the end of this standard.



C1293/C1293M Test Method for Determination of Length Change of Concrete Due to Alkali-Silica Reaction

C1567 Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)

C1866 Specification for Ground-Glass Protectant for Use in Concrete

2.2 ACI Standard²

ACI 318 Building Code Requirements for Structural Concrete and Commentary

2.3 AASHTO Standard³

AASHTO R 80 Standard Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deteriorous Expansion in New Concrete Construction⁴

2.4 CSA Standard⁵

A23.2-26A Determination of Potential Alkali-Carbonate Reactivity of Quarried Carbonate Rocks by Chemical Composition

A23.2-27A Standard Practice to Identify Degree of Alkali Aggregate Reactivity of Aggregates and to Identify Measures to Avoid Deteriorous Expansion in Concrete

A23.2-28A Standard Practice for Laboratory Testing to Demonstrate the Effectiveness of Supplementary Cementitious Materials and Lithium-Based Admixtures to Prevent Alkali-Silica Reaction in Concrete

3. Terminology

3.1 Definitions

3.1.1 For definitions of terms used in this Guide, refer to Terminology C125, Terminology C219, and Descriptive Nomenclature C294.

3.2 Definitions of Terms Specific to This Standard

3.2.1 *alkali content*, Na_2Oeq , n —value in percent determined by reporting sodium and potassium oxides, determined using procedures for total alkali in Test Methods C114, of cement or supplementary cementitious material, using the following formula:

$$\text{Na}_2\text{Oeq} = \frac{1}{2}(\text{Na}_2\text{O} + \frac{1}{2}\text{K}_2\text{O})$$

3.2.2 *alkali loading*, n —amount of alkalis contributed by the cement in a concrete mixture, expressed in kg/m^3 or lb/yd^3 and calculated by multiplying the cement content of the concrete in kg/m^3 or lb/yd^3 by the alkali content of the portland cement, or the portland cement and limestone portion of a blended cement, divided by 100.

3.2.2.1 *Discussion*—Alkali loading is abbreviated as KGA (LBA). In concrete that includes supplementary cementitious materials, only the alkali content of the cement fraction of the cementitious materials is included in the calculation of alkali loading. For example, in a concrete containing $350 \text{ kg}/\text{m}^3$ [590

² Available from American Concrete Institute (ACI), P.O. Box 9094, Farmington Hills, MI 48333-9094, <http://www.concretel.org>.

³ Available from American Association of State Highway and Transportation Officials (AASHTO), 444 N. Capitol St., NW, Suite 340, Washington, DC 20001, <http://www.transportation.org>.

⁴ Available from Canadian Standards Association (CSA), 1887 Spectrum Way, Suite 100, Mississauga, ON, L4W 4N4, Canada, <http://www.csacan.ca>.

lb/yd^3] of cementitious materials consisting of 75 % portland cement, 20 % slag, and 5 % silica fume, and where the alkali content of the portland cement is 0.89 % Na_2Oeq , the alkali loading of the concrete is calculated as follows:

$$\text{KGA} = 350(75/100)(0.89/100) = 2.0 \text{ kg}/\text{m}^3$$

$$[\text{LBA} = 590(75/100)(0.89/100) = 3.9 \text{ lb}/\text{yd}^3]$$

In a concrete containing $355 \text{ kg}/\text{m}^3$ [600 lb/yd^3] of Type IS(25) blended cement, with a base portland cement equivalent alkali content of 0.73 %, the alkali loading of the concrete is calculated as follows:

$$\text{KGA} = 355(75/100)(0.73/100) = 1.9 \text{ kg}/\text{m}^3$$

$$[\text{LBA} = 600(75/100)(0.73/100) = 3.3 \text{ lb}/\text{yd}^3]$$

In a concrete containing $350 \text{ kg}/\text{m}^3$ [590 lb/yd^3] of Type IL(10) portland-limestone cement, with an equivalent alkali content of the finished cement of 0.80 %, the alkali loading of the concrete is calculated as follows:

$$\text{KGA} = 350(80/100)/100 = 2.8 \text{ kg}/\text{m}^3$$

$$[\text{LBA} = 590(80/100)/100 = 4.7 \text{ lb}/\text{yd}^3]$$

In a concrete containing $353 \text{ kg}/\text{m}^3$ [600 lb/yd^3] of Type IT(P3D)(1,10) ternary blended cement, with an equivalent alkali content of the portland cement and limestone fraction of 0.80 %, the alkali loading of the concrete is calculated as follows:

$$\text{KGA} = 353(70/100)(0.80/100) = 2.0 \text{ kg}/\text{m}^3$$

$$[\text{LBA} = 600(70/100)(0.80/100) = 3.4 \text{ lb}/\text{yd}^3]$$

The alkali content of the portland cement and limestone fraction of a Type II, or Type IT blended cement as illustrated in the example calculations above can typically be obtained on request from the manufacturer, even when this information is not reported on a mill test report. It can also be determined independently for a Type II, portland-limestone cement through testing a sample obtained by the user according to Test Method C114.

3.2.3 *cement*, n —portland cement, portland-limestone cement, or the portland cement and limestone portion of a blended cement.

3.2.3.1 *Discussion*—This definition does not include slag cement because alkalies present in slag cement are not included in alkali loading calculations as shown in 3.2.2.1.

3.2.4 *deterioratively reactive*, n —used to describe aggregates that undergo chemical reactions that subsequently result in premature deterioration of concrete.

3.2.4.1 *Discussion*—The term used in this standard guide describes aggregates that undergo chemical reactions with hydroxide (OH^-) in the pore solution.

3.2.5 *non-reactive*, n —used to describe materials that do not undergo chemical reactions that subsequently result in premature deterioration of concrete.

3.2.5.1 *Discussion*—Some aggregates with minor amounts of reactive constituents may exhibit the symptoms of alkali-aggregate reaction (AAR) without producing any damage to the concrete; these are termed as non-reactive aggregates.

4. Summary of Guide

4.1 Alkali-aggregate reactions (AAR) occur between the alkali hydroxides in the pore solution of concrete and certain

components found in some aggregates. Two types of AAR are recognized depending on the nature of the reactive component: alkali-silica reaction (ASR) involves various types of reactive siliceous (SiO_2 containing) minerals and alkali-carbonate reaction (ACR) involves certain types of rocks that contain dolomite [$\text{CaMg}(\text{CO}_3)_2$]. Both types of reaction can result in expansion and cracking of concrete elements when exposed to moisture, leading to a reduction in the service life of concrete structures.

4.2 This guide describes approaches for identifying potentially deleteriously reactive aggregates and selecting appropriate preventive measures to minimize the risk of expansion when such aggregates are used in concrete in exposure environments where AAR may be of concern. Preventive measures include avoiding use of the reactive aggregate, limiting the alkali loading of the concrete, using supplementary cementitious materials, using lithium-based admixtures, or a combination of these strategies.

5. Significance and Use

5.1 This guide provides recommendations for identifying the potential for deleterious AAR and selecting appropriate preventive measures, based on a prescriptive-based or performance approach. To minimize the risk of deleterious reaction, in regions where occurrences of AAR are rare or the aggregate sources in use have a satisfactory field performance record verified by following the guidance in this standard, it is reasonable to continue to rely on the previous field history without subjecting the aggregates to laboratory tests for AAR. In regions where AAR problems have occurred or the reactivity of aggregates is known to vary from source to source, it may be necessary to follow a testing program to determine potential reactivity and evaluate preventive measures. In this guide, the level of prevention required is a function of the reactivity of the aggregate, the nature of the exposure conditions (especially availability of moisture), the criticality of the structure, and the availability of alkali in the concrete.

5.2 Risk Evaluation—To use this guide effectively, it is necessary to define the level of risk that is acceptable, as this will determine the type and complexity of testing (Note 1). The risk of deleterious expansion occurring as a result of a failure to detect deleteriously reactive aggregates can be reduced by routine testing using petrography, or laboratory expansion tests, or both.

Note 1—The level of risk of alkali-silica reaction will depend upon the nature of the project (criticality of the structure and anticipated exposure). The determination of the level of risk is the responsibility of the individual in charge of the design, commonly a representative of the owner, and for structures designed in accordance with ACI 318, the level of acceptable risk would be determined by the licensed design professional.

5.3 For conventional structures, preventive measures determined by either performance testing or the prescriptive approach described in this guide can be expected to generally reduce the risk of expansion as a result of ASR to an acceptable level. For certain critical structures, such as those exposed to continuous moisture (for example, hydraulic dams or power plants), in which ASR-related expansion cannot be tolerated, more conservative mitigation measures may be warranted.

5.4 There are no proven measures for effectively preventing damaging expansion with alkali carbonate reactive rocks in concrete and such materials need to be avoided.

5.5 If an aggregate is identified as potentially deleteriously reactive as a result of ASR, and the structure size, class, and exposure condition requires preventive measures, the aggregate may be accepted for use together with appropriate preventive measures following the prescriptive or performance methods outlined in this guide.

6. Procedure

6.1 The flow chart in Fig. 1 shows the general sequence of testing and decisions that should be made when evaluating a source of aggregate for potential AAR. Solid lines show the approach recommended for a lower risk of AAR. The amount and time of testing can be reduced with acceptance of a higher level of risk following the flow chart along the dashed lines. Prior documented satisfactory field performance of the aggregate in concrete is generally considered to be sufficient for its acceptance in new concrete. However, reliance on prior field performance without following the guidance and recommended testing in 7.1 may not be sufficient to safeguard against damage as a result of AAR in new construction. This is due to the difficulties in assuring that the materials and mixture proportions used in existing structures built 10 to 20 years ago (the time frame needed to ensure that a deleterious reaction as a result of AAR has not occurred) are similar to those being proposed for use today. In most cases, it will be necessary to perform laboratory tests to determine whether the aggregate is potentially deleteriously reactive for the specific concrete mixture to be used.

6.1.1 It is recommended that the potential AAR of a new or not previously tested source be established following the solid lines from beginning to end of the flow chart. There are several test methods available for evaluating potential AAR. Petrographic examination, determination of chemical constituents, and mortar bar and concrete prism expansion tests are recommended in this guide. If there are no changes in the geologic uniformity of the deposit or mineralogical composition, then the aggregate could be subsequently monitored using a revised approach based on interpretation of the initial test results (see 7.7). A revised approach would allow for the omission of tests based on suitable existing data, or for omission of less reliable tests if more reliable tests are being performed.

6.2 If the aggregate is deemed to be non-reactive, it can be accepted for use in concrete with no further consideration of mitigation provided that the other physical properties of the aggregate render it suitable for use (refer to Specification C31/C31M). If the aggregate is a quarried carbonate, tests are required to determine whether the potential reaction is of the alkali-carbonate or alkali-silica type. Aggregate deemed alkali carbonate reactive should be avoided. Aggregate deemed alkali-silica reactive can be tested for efficacy of preventive measures. Steps for selecting appropriate preventive measures for ASR follow either a performance-based (Section 8) or prescriptive-based (Section 9) approach. In the performance-based approach, a potential preventive measure is tested to determine if the measure provides a reduction in expansion

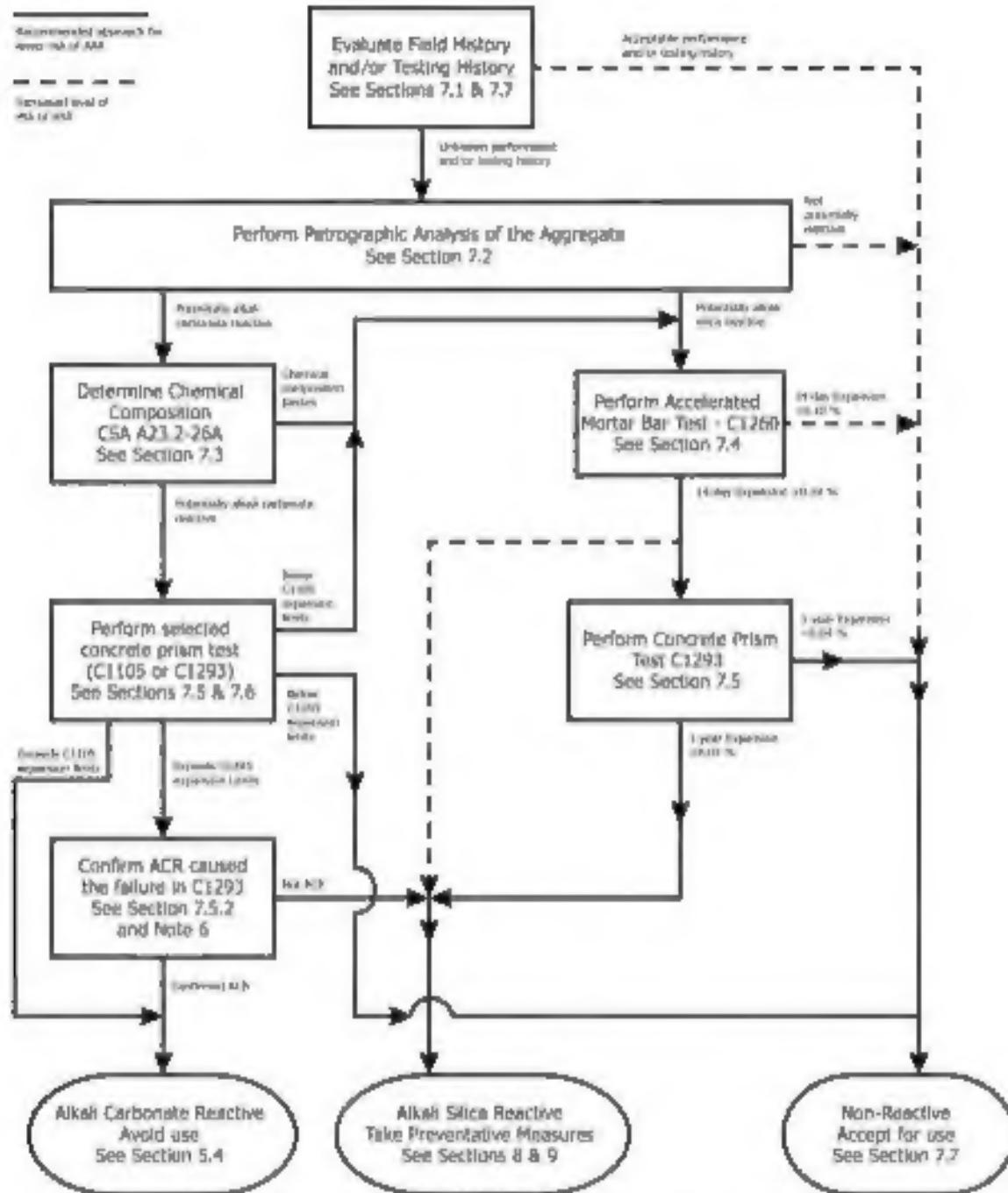


FIG. 1 Sequence of Laboratory Tests for Evaluating Aggregate Reactivity

below the limits outlined in this guide. Both approaches are intended to minimize the potential for deleterious expansion in field concrete.

7. Determining Aggregate Reactivity

7.1 Use of Field Performance History

7.1.1 The long-term field performance history of an aggregate can be established by surveying existing structures that were constructed using the same aggregate source. As many structures as practical should be included in the survey and these structures should, if possible, represent different types of

construction (for example, foundations, walls, bridges, pavements, sidewalks, and structural elements). Procedure C823M provides useful guidance when surveying structures to establish field performance history. The following information should be documented for each structure:

- 7.1.1.1 Age—Structures should be at least 15 years old as visible damage from AAR can take more than ten years to develop.
- 7.1.1.2 Alkali loading of the concrete.
- 7.1.1.3 Use and content of pozzolans or slag cement or blended cements during construction.

7.1.1.4 *Exposure Condition*—Availability of moisture and use of deicing chemicals.

7.1.1.5 *Symptoms of distress observed*.

7.1.2 Cores should be taken from a representative number of these structures and a petrographic examination conducted using Practice C856 to establish the following (Note 2):

7.1.2.1 The aggregate used in the structure surveyed is of similar mineralogical composition, as determined by Guide C295/C295M, to that of the aggregate to be used;

7.1.2.2 Any evidence of damage as a result of AAR; and

7.1.2.3 The presence, quantity, and composition (if known) of fly ash, slag cement, or other supplementary cementitious materials.

Note 2—Even if signs of deterioration are not observed, cores should be taken to establish uniformity of materials.

7.1.3 If the results of the field survey indicate that the aggregate is non-reactive, the aggregate may be used in new construction provided that the new concrete is not produced with a higher concrete alkali content, a lower replacement level of supplementary cementitious material (SCM), or placed in a more aggressive exposure condition than the structures included in the survey.

7.1.4 There is a certain level of uncertainty associated with accepting aggregates solely on the basis of field performance because of difficulties in establishing unequivocally that the materials and proportions used more than 10 to 15 years ago are sufficiently similar to those to be used in new construction. If field performance indicates that an aggregate source is potentially deleteriously reactive, laboratory testing can be conducted to determine the level of aggregate reactivity and evaluate preventive measures. The use of long-term performance is considered to be a reliable method in determining the

suitability of an aggregate; however, it is often very difficult to acquire the necessary information and background for existing structures.

7.2 *Petrographic Assessment*:

7.2.1 Petrographic examination of aggregates should be conducted in accordance with Guide C203/C203M. Petrography can reveal useful information about the composition of an aggregate, including the identification and approximate amount of potentially reactive minerals. Petrography can be used to classify an aggregate as potentially reactive, but expansion testing is required to determine the extent of the reactivity and appropriate mitigation measures. Aggregates may be accepted as non-reactive solely on the basis of petrography, but there is a certain level of uncertainty associated with such a decision. For example, some reactive phases may not be detected by optical microscopy. If a petrographer is examining aggregates from well-known and tested sources, it is reasonable to use petrography to classify the aggregate reactivity on a routine basis.

7.2.2 Petrographers should look for alkali-reactive silica components such as opal, chert, chalcedony, cristobalite, strained and micro-crystalline quartz, and volcanic glass. Petrographers should also ascertain the presence of mineralogical and textural features characteristic of alkali-carbonate reactive aggregates. Deleteriously reactive alkali-carbonate aggregates often exhibit a characteristic microscopic texture consisting of dolomite rhombs within a fine-grained matrix of calcite, quartz, and clay (3). However, there have

³ The boldface numbers in parentheses refer to the list of references at the end of this standard.

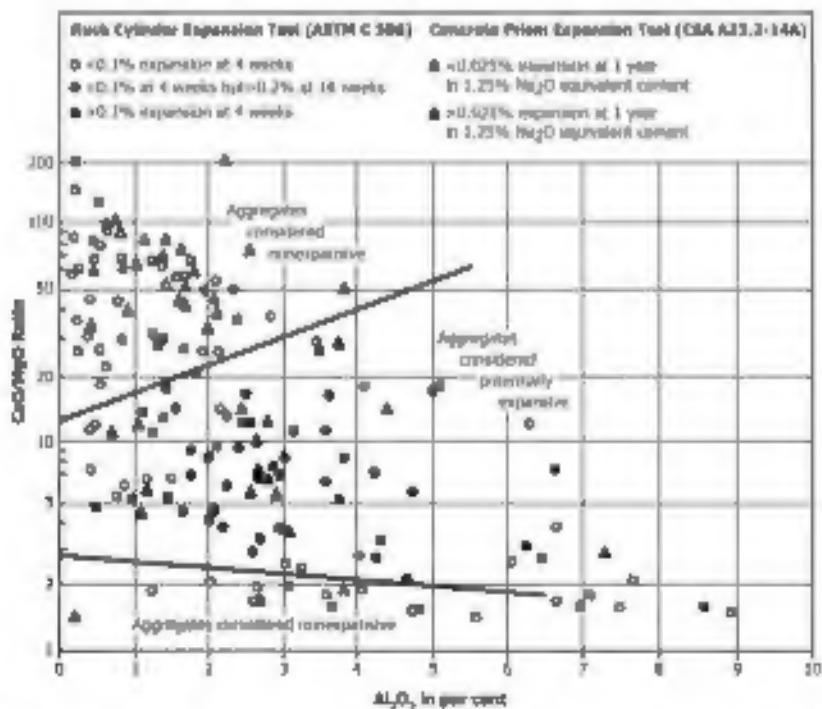


FIG. 2 Plot of CaO/MgO Ratio Versus the Al₂O₃ Content of Quarried Carbonate Rocks (1)

been reports of deleterious ACR with aggregates that do not exhibit this "classic" texture (3).

7.3 Determination of Potential Alkali-Carbonate Reactive Rocks by Chemical Composition, CSA A23.2-26A—If the aggregate being assessed is a quarried carbonate rock, the potential for ACR may be assessed on the basis of its chemical composition (1). This test involves the determination of lime (CaO), magnesium (MgO), and alumina (Al_2O_3) contents of the rock and determining where the composition of the rock falls on a plot of CaO/MgO ratio versus the Al_2O_3 content, as shown in Fig. 2.

7.3.1 If the composition does not fall in the range of "aggregates considered to be potentially expansive" in Fig. 2, the aggregate is considered to be not potentially alkali-carbonate reactive and should be tested using the options for evaluation of potential alkali-silica reactivity outlined in this guide.

7.3.2 If the composition falls in the range of "aggregates considered to be potentially expansive" in Fig. 2, the aggregate is considered to be potentially alkali-carbonate reactive. Such aggregates may be tested using either of the following concrete prism tests: Test Method C1293/C1293M or C1105 using a low-alkali content (see 7.5 and 7.6).

7.4 Accelerated Mortar Bar Test, Test Method C1260—This test method is suitable for assessing potentially alkali-silica reactive aggregates (Note 3).

Note 3: Test Method C1260 (accelerated mortar bar test) is not suitable for detecting ACR in aggregates that are alkali-carbonate reactive, may not expand when exposed to the conditions used in Test Method C1260.

7.4.1 If mortar bars in this test expand by less than 0.10 % after 14 days immersion, the aggregate is considered to be innocuous according to this test. (Note 4) (4-6).

Note 4: Coarse aggregate for Test Method C1260 is crushed to sand size (<3 mm [12.2 in.]) and then washed and graded to meet the grading requirements of the test method. Sands are washed and graded to meet the same grading requirements. The test is intended to evaluate coarse and fine aggregate separately and should not be used to evaluate job combinations of coarse and fine aggregates.

7.4.2 If the mortar bars expand 0.10 % or greater after 14 days immersion, the aggregate is considered to be potentially deleteriously reactive (Note 5) (4, 7, 8), and it is recommended to confirm reactivity in concrete using Test Method C1293/C1293M (concrete prism test) (Note 5 and Note 6).

Note 5: If expansion by 0.10 % or greater occurs, it is recommended to confirm that the expansion is actually due to alkali-silica reaction using supplementary information. Sources of supplementary information include: (1) petrographic examination of the aggregate in accordance with Guide C295/C295M to determine if known reactive constituents are present; (2) examination of the specimens after test in accordance with Practice C856 to identify the products of alkali-silica reaction; and (3) if available, field service or previous test records to assess performance.

Note 6: Test Method C1260 may give a false-negative result for some slowly reactive aggregates, aggregates with peruvianite effect, and/or aggregates containing deleterious strained quartz when microcrystalline quartz is also present (9). Some granite granules, orthoquartzite and metapelites have been found to be deleteriously expansive in field performance even though their expansion in this test was less than 0.10 % (7, 10). For this aggregate type, it is recommended that prior field performance be investigated. In the absence of field performance data, the aggregate reactivity should be further evaluated using Test Method C1293/C1293M or mitigative measures should be taken following the prescriptive approach outlined in Section 9.

Note 7: The potential reactivity of various varieties of quartz may not be accurately determined by Test Method C1260 since the test method may produce a false-positive result with a number of aggregates that have shown mixed results in field performance (8). For aggregates producing false positives with Test Method C1260, Test Method C1567 may also provide overly conservative estimates of the amount of SCM to control ASR. These aggregates are those plotting in Zone 1 of Fig. 3 if Test Method C1260 and Test Method C1293/C1293M results for the same aggregate are compared.

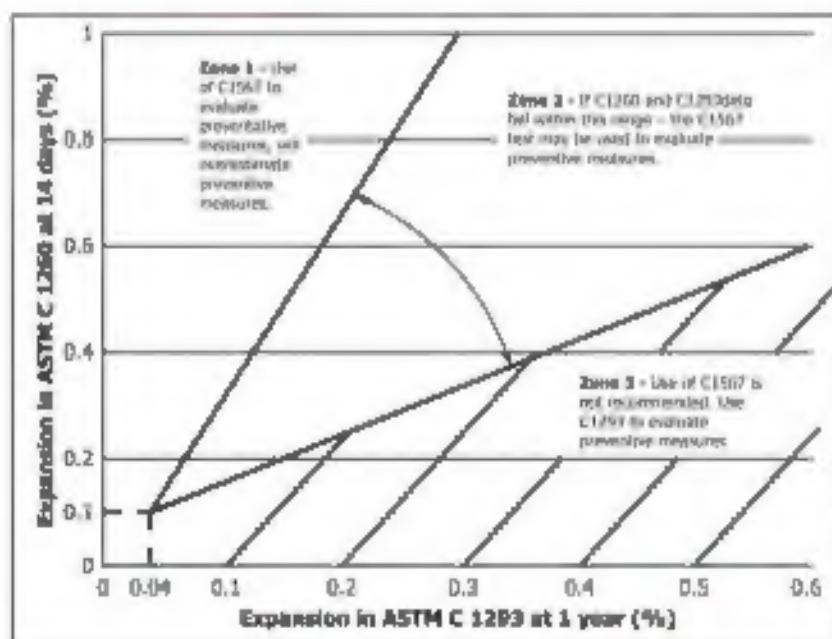


FIG. 3 Comparison of Test Method C1260, Accelerated Mortar Bar, and Test Method C1293/C1293M, Concrete Prism Test, Data for Purpose of Determining Whether Test Method C1567 is Suitable for Evaluating Preventative Measures with a Specific Aggregate

7.5 Concrete Prism Test, Test Method C1293/C1293M—

This concrete prism test is suitable for evaluating potentially alkali-silica reactive aggregates and alkali-carbonate reactive aggregates. It is considered by many researchers to be the most reliable laboratory test for predicting field performance of aggregates (11). If the potentially reactive aggregate being tested is a coarse aggregate, use a non-reactive fine aggregate and vice versa. The coarse-fine aggregate combination should be used to make concrete prisms with a specified high-alkali loading. The test is intended to evaluate coarse and fine aggregates separately and should not be used to evaluate job combinations of coarse and fine aggregates.

7.3.1 If concrete prisms in this test expand by less than 0.04 % after one year, the aggregate is considered non-reactive and may be used in concrete with no further testing for AAR.

7.5.2 If the prisms expand by 0.04 % or greater at one year, the aggregate is considered to be potentially deleteriously reactive and preventive measures, as outlined in Section 8 or 9, are required if the aggregate is to be used in concrete construction for structures and exposure conditions requiring preventive measures (Note 8).

Note 6.—Supplemental information may be obtained by performing a petrographic examination, in accordance with Practice C858, of the concrete pieces after the test is completed. This examination can be used to confirm that alkali-silica reaction products from the coarse or fine aggregate being tested are present and attributed to the expansion, and to identify if other reaction mechanisms are present and contributing to expansion.

7.5.3 If the aggregate tested is a quarried carbonate rock with a chemical composition that falls within the region in (Fig. 2), labeled as "aggregate considered to be potentially reactive," and exhibited concrete prism expansion of 0.04 % or greater in one year, and was not tested using Test Method C1105 (see 7.6), the concrete prisms should be examined to determine whether ACR contributed to the expansion or additional testing may be warranted (Note 9). If damaging ACR is detected, either in isolation or in combination with ASR, the aggregate should not be used in concrete without selective quarrying or aggregate processing to limit the alkali-reactive carbonate components to acceptable levels.

NOTE 9.—The determination of the extent to which the ACR is contained in the expansion of the concrete should be conducted by an expert having experience with ACR. Methods may include one or more of the following: petrographic examination of the concrete (Practice C836), accelerated cylinder testing of the aggregate (12), or rock cylinder expansion tests (Test Method C838) conducted on samples of rock from the quarry.

7.5.4 If an aggregate is reactive according to Test Method C1293AC1293M, and is to be used in concrete construction, appropriate preventive measures need to be taken following the procedures outlined in Sections 8 or 9.

7.5 Concrete Prism Test for Alkali-Carbonate Reaction Test

Method C110S—For quarried carbonate rocks with compositions falling within the region of "aggregates considered to be potentially reactive" in Fig. 2, this concrete prism test for alkali-carbonate reaction may also be used, but the alkali loading of the concrete should be kept below 1.8 kg/m³ [3.0 lb/yd³] to minimize the risk of deleterious expansion as a result of ASR.

7.6.1 If the expansion results from Test Method C1105 are 0.025 % or greater at six months or are 0.030 % or greater at twelve months, the aggregate is considered to be alkali-carbonate reactive and its use in concrete is to be avoided (Note 10). If the expansion results do not exceed these values, the aggregate is considered to be not alkali-carbonate reactive but should be tested for alkali-silica reactivity as outlined in this guide.

Nursing—It is recommended that the test be conducted for a period of twelve months, but extension beyond six months can be used if needed.

7.7 Interpretation of Results from Laboratory Tests and use of Existing Tests—Use Fig. 1 to interpret the results from existing laboratory and field testing and to make decisions regarding the risk of alkali-silica or alkali-carbonate reaction occurring in concrete.

7.7.1 Fig. 1 shows dotted lines from the boxes marked "Evaluate Field History and/or Testing History," "Perform Petrographic Analysis of the Aggregate," and "Perform Accelerated Mortar Bar Test" to the box marked "Non-Reflective Accept for Use" as there is an element of uncertainty associated with accepting aggregates solely on the basis of these tests. With some aggregates, it may not be possible to identify reflective constituents by petrographic examination.

7.7.2 Test Method C1260 is generally recognized as a relatively severe test that identifies as potentially deleteriously reactive many aggregate sources that have a history of satisfactory field performance and that Test Method C1293/C1293M identifies as non-reactive. For this reason, results from Test Method C1260 should not be used to reject an aggregate. If an aggregate is potentially reactive based on the results of Test Method C1260 (expansion $\geq 0.10\%$ after 14 days immersion), its reactivity should be confirmed by testing using Test Method C1293 or the potentially reactive aggregate should be used with appropriate mitigation measures (Section 8 or 9). If the results of Test Methods C1260 and C1293/C1293M are in disagreement, the results of Test Method C1293/C1293M should be considered the more reliable.

Although there were exceptions, in the past, it was often assumed that aggregates that passed Test Method C1260 (expansion < 0.10 % after 14 days immersion) were most likely to pass Test Method C1293/C1293M (expansion < 0.04 % at 1 year), and such aggregates could be accepted for use in concrete without the need for confirmatory testing using Test Method C1293/C1293M. However, there have been an increasing number of coarse aggregates that have been found to pass Test Method C1260 and fail Test Method C1293/C1293M and this is somewhat disconcerting for specifications that permit the use of aggregates passing Test Method C1260 with no further testing (that is, no requirements for Test Method C1293/C1293M) (Note 11) (13) (14). Consequently, there is a risk associated with accepting an aggregate solely on the basis of the results from Test Method C1260.

NOTE 11.—Several agencies have extended the duration of Test Method C1260 and the WI Endpoint limit of 0.10% to even 0.05% after 38 days (attributed to 1/4 NaOH at 80 °C [176 °F]). This more lenient requirement should not be adopted unless it can be demonstrated that extension of the test period is required by capture aggregates that are believed to be similar to those that have been identified as being deleteriously reactive either by

concrete prism testing or field performance. Applying the extended test duration to all aggregates may result in an unacceptable number of cases in which the accelerated mortar bar test results in false positives. Note that extending the test duration does not capture all of the aggregates that have been found to pass Test Method C1260 but fail Test Method C1293/C1293M.

7.7.3 In Fig. 1, Test Method C1260 is shown with a broken line, as there is the possibility of incorrectly identifying a deleteriously reactive aggregate as being non-reactive using this method. The most reliable approach for determining aggregate reactivity is to use Test Method C1293/C1293M for all cases (that is, to exclude Test Method C1260 from the evaluation process). However, it is recognized that the long duration of Test Method C1293/C1293M makes it impractical for use in many circumstances and there is a need for a more rapid test.

8. Performance-based Approach for Selecting Appropriate Preventive Measures

8.1 In the performance-based approach, the efficacy of the preventive measure in combination with the reactive aggregate is tested using either Test Method C1293/C1293M or Test Method C1567 (Note 12). This approach is suitable for selecting the appropriate level of supplementary cementitious materials (SCMs). The effect of different alkali loadings on the performance of concrete mixtures made with reactive aggregates cannot be determined using Test Methods C1293/C1293M and C1567, nor can these tests be used to determine a maximum safe alkali loading (see Note 13). Mitigation measures using limits on alkali loading should be determined using Section 9.

Note 12—Currently, there is no ANTM standard analogous to Test Method C1567 for testing the efficacy of lithium. Research is underway to establish a standardized method as well as precision and bias statements. However, several agencies (American Association of State Highway and Transportation Officials (AASHTO), Federal Highway Administration (FHWA), and Canadian Standards Association (CSA)) specify testing procedures to evaluate the efficacy of lithium nitrate to control alkali-silica reaction in concrete specimens. Guidance on these testing procedures can be found in AASHTO R 80, CSA A23.2-29A, and an FHWA Report (15).

8.2 Performance Testing Using Test Method C1293/C1293M—The ability of SCMs such as fly ash, slag cement, silica fume, ground-glass pozzolan, and natural pozzolans, to control deleterious expansion with a reactive aggregate can be evaluated using Test Method C1293/C1293M. When testing SCMs, the total cementitious materials content is maintained at 420 kg/m³ (708 lb/yd³), but the cement is replaced partially with the desired amount of the SCM (or combination of SCMs) under investigation. The alkali content of the cement component of the mixture (as defined in 3.2.3) only is raised to 1.25 % Na₂Oeq (Note 13). A number of tests should be conducted using varying levels of SCMs to optimize the proportions that will meet the expansion criteria. The test duration for evaluating preventive measures is two years. If expansions are <0.04 % at two years, the combination of SCM and reactive aggregate is considered suitable for use in concrete construction.

Note 13—The expansion of concrete prisms produced with portland cement (Specification C150/C150M Type I) with the alkali content raised to 1.25 % Na₂Oeq provides a reliable prediction of the field expansion of concrete produced with portland cements with alkali contents up to 1.0 % Na₂Oeq. If the cement to be used in the field has an alkali content above 1.00 % Na₂Oeq, this same cement should be used for the concrete prism test and the alkali content should be raised by 0.25 % Na₂Oeq by the addition of NaOH to the mix water (16). Due to the potential for alkali leaching from the concrete prisms during storage, there is no simple way to modify Test Method C1293/C1293M (concrete prism test) to provide a reliable evaluation of the beneficial effects of using a concrete with low alkali loading.

8.3 Performance Testing Using Test Method C1567—Test Method C1567 was developed specifically for "determining the potential alkali-silica reactivity of combinations of cementitious materials and aggregates." Before Test Method C1567 can be used to determine the performance of a specific SCM-aggregate combination, it is recommended that it first be demonstrated that the reactivity of the aggregate being evaluated is properly identified. It is recommended that the aggregate reactivity be evaluated using results from Test Method C1260 and Test Method C1293/C1293M for the aggregate being used without preventive measures. After subjecting the aggregate to both tests, the results are plotted on Fig. 3. Provided data do not fall within Zone 3 indicated in Fig. 3, Test Method C1567 can then be used to determine the efficacy of SCMs. Neglecting to perform this type of comparison may result in either (1) an overly conservative estimate of aggregate reactivity using Test Method C1260 resulting in overestimation of required SCM amounts or (2) a less conservative estimate of aggregate reactivity using Test Method C1260 resulting in underestimation of required SCM amounts. This represents an inherent risk in relying solely on the results of Test Method C1260 or Test Method C1567. It is recommended that Test Methods C1260 and C1293/C1293M be compared regularly (every two years would be a conservative recommendation) unless the results of petrography or other tests indicate a significant change in the composition of the material in the quarry, in which case, new tests should be initiated (15).

8.3.1 Combinations of cementitious materials and aggregates will be deemed acceptable for use if the resulting expansion is <0.10 % after 14 days immersion in 1N NaOH (Note 14, Note 15) (5, 6).

Note 14—This test method is not suitable for evaluating SCMs with high alkali contents (fly ash and ground-glass pozzolan with >0.9 % Na₂Oeq and slag cement or silica fume with >1.0 % Na₂Oeq). Such materials should be evaluated using the Test Method C1293/C1293M. Also, since mortar bars are immersed in 1.0 N NaOH solution (equivalent to a portland cement with approximately 1.4 % Na₂Oeq), Test Method C1567 (accelerated mortar bar test) is not suitable for evaluating ASR mitigation by reducing alkali loading.

Note 15—Results obtained using Test Method C1567 may overestimate the reactivity of some types of aggregates if used in service with the same combination of pozzolans or slag cement but having a hydraulic cement with an alkali content <0.7 % Na₂Oeq.

8.3.2 An expansion of 0.10 % or greater at 14 days immersion indicates the combination of materials was not adequate to mitigate expansive ASR of the aggregate being tested (5, 6).

Expansion may be reduced by retesting the material combination at higher SCM replacement levels.

9. Prescriptive Approach for Selecting Appropriate Preventive Measures

9.1 Using the prescriptive approach, the level of prevention is determined by considering the class (criticality of structure), size, and exposure condition of the structure; the degree of aggregate reactivity; and the alkali loading of the concrete. The approach follows the prescriptive requirement in Tables 1-8. This approach is similar to that originally developed in Canada (CSA A23.2-27A) and being developed in Europe (17). It is also similar to the current guidance in AASHTO R 80.

9.1.1 The prescriptive approach is suitable for selecting the appropriate level of SCM, the maximum alkali loading, or both of the concrete. It can be used as an option if complete performance test data are not available.

9.1.2 *Degree of Alkali-Silica Reactivity*—The degree of alkali-silica reactivity of an aggregate is determined by testing the aggregate in accordance with Test Method C1293/C1293M and using the expansion value at one year. Aggregate-reactivity classes are given in Table 1. If data from Test Method C1293/C1293M are not available, data from Test Method C1260 may be used to classify aggregate reactivity as shown in Table 1. If the coarse and fine aggregates are of different reactivity, the level of prevention should be selected on the basis of the more reactive aggregate.

9.1.3 *Level of ASR Risk*—The risk of ASR occurring in a structure can be determined by considering the aggregate reactivity and the exposure conditions using Table 2. The guidance provided in Table 2 can be used in the absence of other information regarding exposure conditions of a particular structure and is meant as an aid to choosing the proper prescriptive approach to minimize the potential for deleterious ASR.

9.1.4 *Determining the Level of Prevention*—By considering the risk of ASR from Table 2 combined with the class of structure from Table 3, the level of prevention required is determined from Table 4.

9.1.5 Identification of Preventive Measures

9.1.5.1 *Option 1: Limiting the Alkali Loading of the Concrete*—The potential for damaging ASR can be minimized by limiting the alkali loading of the concrete. Maximum permissible alkali loadings are given in Table 5. The alkali loading of concrete is calculated as described in 3.2.2.

9.1.5.2 *Option 2: Using SCM*—The potential for damaging ASR can be minimized by using a sufficient quantity of a suitable SCM such as fly ash, slag cement, silica fume, or natural pozzolan (Note 16). Table 6 provides minimum replacement levels for fly ash with less than 18 % CaO deter-

TABLE 2 Determining the Level of ASR Risk

Size and Exposure Conditions	Aggregate-Reactivity Class			
	R0	R1	R2	R3
Non-massive ^a concrete in a dry ^b environment	Level 1	Level 1	Level 2	Level 3
Massive ^c elements in a dry ^b environment	Level 1	Level 2	Level 3	Level 4
All concrete exposed to humid air, buns or immersed	Level 1	Level 3	Level 4	Level 5
All concrete exposed to alkalies in service ^d	Level 1	Level 4	Level 5	Level 6

^aA massive element has a least dimension of greater than 0.9 m (3 ft).

^bA dry environment corresponds to an average ambient relative humidity lower than 60 %, normally only found in the interior of buildings.

^cExamples of structures exposed to alkalies in service include marine structures exposed to seawater and highway structures exposed to deicing salts (for example, NaCl) or anti-icing salts (for example, potassium acetate, sodium formate, and so forth).

mined in accordance with Specification C311/C311M and meeting the requirements of Specification C618, silica fume with more than 83 % SiO₂, and meeting the requirements of Specification C1240, and slag cement meeting the requirements of Specification C989/C989M. Fly ashes with more than 18 % CaO can be used to mitigate ASR; however, their effectiveness should be evaluated following the performance-based approach outlined in 8.2 and 8.3. When two or more SCMs are used together to control ASR, the minimum replacement levels given in Table 6 for the individual SCMs may be reduced provided that the sum of proportions of both SCMs is greater than or equal to one. For example, when silica fume and slag are used together, the silica fume level may be reduced to one third of the minimum silica fume level given in Table 6 provided that the slag level is at least two thirds of the minimum slag level.

Note 16—Many natural pozzolans, such as metakaolin, calcined clays, shales, and volcanic ash have been known to be effective in controlling expansion as a result of ASR. However, no prescriptive measures are provided for natural pozzolans in Table 6 as this class of materials covers a wide variety of pozzolan types with a broad range of properties. When natural pozzolans are to be used to control ASR, the efficacy of the particular aggregate-pozzolan combination should be determined by performance testing.

The minimum replacement levels in Table 6 are appropriate for use with cements of moderate-to-high alkali contents (0.7 to 1.0 % Na₂Oeq). Table 7 provides recommendations for adjusting the level of SCM when the alkali content of the cement is above or below this range (16). When SCMs are combined with lower alkali cements (<0.7 % Na₂Oeq), the risk is sufficiently low to adopt the value of the minimum replacement level for the next prevention level down. For example, if slag cement is to be used in Prevention Level Y with lower alkali cement, the level of slag cement can be reduced to the level specified for Prevention Level X (35 %). The replacement levels used should not be below those given in Table 6 for Prevention Level W, regardless of the alkali content of the cement. Similarly, if higher alkali cements (>1.0 % Na₂Oeq) are used together with SCMs, the replacement level of SCM should be increased to that required for the next prevention level up. For example, if slag cement is to be used in Prevention Level Y with higher alkali cement, the level of slag cement should be increased to the level specified for Prevention Level Z (65 %).

TABLE 1 Classification of Aggregate Reactivity

Aggregate-Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in Test Method C1293/C1293M, %	14-Day Expansion in Test Method C1260, %
R0	Non-reactive	<0.04	<0.10
R1	Moderately reactive	≥0.04, <0.12	≥0.10, <0.30
R2	Highly reactive	≥0.12, <0.24	≥0.30, <0.45
R3	Very highly reactive	≥0.24	≥0.45

**TABLE 3 Structures Classified on Basis of the Severity of Consequences Should ASR¹ Occur
(Modified for Highway Structures from RILEM TC 101-ARP)**

Class	Consequences of ASR	Acceptability of ASR	Examples ²
Class SC1	Safety, economic, or environmental consequences are small or negligible	Some deterioration from ASR may be tolerated	Non-load-bearing elements inside buildings Concrete elements not exposed to moisture Temporary structures (service life < 5 years)
Class SC2	Some safety, economic, or environmental consequences if major deterioration	Minor risk of ASR is unacceptable	Side walls, curbs, and gutters Elements with service life > 40 years
Class SC3	Significant safety, economic, or environmental consequences if minor damage	Minor risk of ASR may be acceptable	Pavements Foundations, piers Retaining walls Columns Highway barriers Rural low-voltage roads Precast elements in which economic costs of replacement are severe Buildings for mobility 40 in 74 years
Class SC4	Severe safety, economic, or environmental consequences if minor damage	ASR cannot be tolerated	Major Bridges Power plants Dams Nuclear facilities Water treatment facilities Waste water treatment facilities Tunnels Critical structures that are very difficult to inspect or repair Buildings for mobility > 75 years

¹This table does not consider the consequences of damage as a result of ACI. This protocol does not permit the use of alkali-calcium aggregates.

²The types of structures listed under each class are typical in service as examples. Some owners may decide to use their own classification system. For example, shoulders, curbs, and gutters may be placed in the SC3 class in some jurisdictions.

TABLE 4 Determining Level of Prevention

Level of ASR Risk (Table 3)	Classification of Structure (Table 3)			
	Class SC1	Class SC2	Class SC3	Class SC4
Risk Level 1	Y	Y	Y	Y
Risk Level 2	Y	Y	N	N
Risk Level 3	Y	N	X	Y
Risk Level 4	Y	N	Y	Z
Risk Level 5	X	Y	Z	ZZ
Risk Level 6	Y	Z	ZZ	A

³It may not be justified to survival a Class SC4 structure (see Table 3) if the risk of ASR is Level 6. Measures should be taken to reduce the level of risk in these circumstances (B).

TABLE 5 Maximum Alkali Loadings to Provide Various Levels of Prevention

Prevention Level	Maximum Alkali Limit of Concrete	
	kg/m ³	lb/yd ³
Y	—	No Limit
W	3.0	5.0
X	3.4	5.0
Y	4.0	6.0
Z ^a	—	Table 6
ZZ ^a	—	Table 6

^aSCMs may be used in Prevention Levels Z and ZZ.

The prescriptive option at this guide should not be used when the alkali content of the cement exceeds 1.25% Na₂Oeq.

9.1.5.3 Option 3: Controlling the Alkali Loading of Concrete and Using SCMs when Highest Levels of Prevention Are Required (Levels Z and ZZ)—If the highest levels of prevention

are needed, a combination of Options 1 and 2 may be required. This approach requires that a minimum level of SCM be used and that a maximum limit be placed on the concrete alkali loading. Options for Prevention Levels Z and ZZ are given in Table 6.

TABLE 6 Minimum Levels of SCM to Provide Appropriate Level of Prevention

Type of SCM ^a	Alkali Content of SCM (% Na ₂ Oeq)	Minimum Replacement Level ^b (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash ^c (CaO ≤ 18 %)	<3.0	15	20	26	35	Table 8
	3.0 – 4.0	20	25	30	40	
	>4.0	25	35	50	65	
Slag Cement	<1.0	—	—	—	—	Table 8
	1.0 – 2.0	2.0 × KGA or 1.2 × LBA	2.5 × KGA or 1.5 × LBA	3.0 × KGA or 1.8 × LBA	4.0 × KGA or 2.5 × LBA	
	>2.0	—	—	—	—	
Silica Fume ^d (SiO ₂ > 95 %)	<1.0	—	—	—	—	Table 8
	1.0 – 2.0	—	—	—	—	
	>2.0	—	—	—	—	

^a The SCM may be added directly to the concrete mixes or it may be a component of a blended cement. Fly ash should meet the requirements of Specification C618, slag cement should meet the specifications of C699/C699M, and silica fume should meet the requirements of Specification C284/C284M or C1157/C1157M. Blended cements should meet the requirements of Specification C595/C595M or C1157/C1157M.

^b Fly ash with greater than 18 % CaO can mitigate ASR. The efficacy of these higher calcium fly ashes should be evaluated using the performance-based testing outlined in 8.2 and 8.3.

^c The minimum level of silica fume (as a percentage of cementing material) is calculated on the basis of the alkali loading of the concrete expressed in either units of kg/m³ (KGA) or kg/m² (LBA). Regardless of the calculated value, the minimum level of silica fume may not be less than 7 % when it is the only method of prevention.

^d Note—the use of high levels of SCM in concrete may increase the risk of problems as a result of slaker ear starting if the concrete is not properly proportioned, blended, and cured.

TABLE 7 Adjusting Minimum Level of SCM Based on Alkali Content of Cement

Cement Alkali Content (% Na ₂ Oeq)	Level of SCM
<0.70	Reduce the minimum amount of SCM given in Table 6 by one prevention level ^a
0.70 to 1.00	Use the minimum levels of SCM given in Table 6
>1.00 to 1.25	Increase the minimum amounts of SCM given in Table 6 by one prevention level
>1.25	No guidance is given

^a The replacement levels should not be below those given in Table 6 for prevention level W, regardless of the alkali content of the cement.

TABLE 8 Using SCM and Limiting Alkali Loading of Concrete to Provide Highest Levels of Prevention

Prevention Level	SCM as sole prevention	Limiting minimum alkali loading plus SCM	
		Minimum SCM level	Maximum alkali loading, kg/m ³ (lb/yd ³)
2	SCM level shown for Level Z in Table 6	1.0 (3.0)	SCM level shown for Level Y in Table 6
ZZ	Not permitted	1.0 (3.0)	SCM level shown for Level Z in Table 6

10. Keywords

10.1 AAR; ACR; alkali-aggregate reaction; alkali-carbonate reaction; alkali-silica reaction; ASR; concrete; concrete durability; laboratory testing; pozzolanic; reactive aggregate; risk evaluation; supplementary cementitious materials

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SUMMARY OF CHANGES

Committee C09 has identified the location of selected changes to this standard since the last issue (C1778-22) that may impact the use of this standard. (Approved December 1, 2023.)

- (7) Revised 3.2.1, 3.2.2, and 3.2.2.1.
(2) Added 3.2.3 and 3.2.3.1.
(3) Revised 4.1.

(4) Revised 4.2.
(5) Revised 4.1.5.1 and 4.1.5.2.
(6) Revised Table 2.

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